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Materials Science and Engineering A 462 (2007) 225–229

MATERIALS SCIENCE & ENGINEERING A

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# Strengthening in a WE54 magnesium alloy containing SiC particles

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Received 19 September 2005; received in revised form 26 January 2006; accepted 28 January 2006

## Abstract

The microstructure and the mechanical properties of the WE54 magnesium alloy reinforced by 13 vol.% of silicon carbide particulates were studied. The composite material was prepared using a powder-metallurgical technique. Compressive deformation properties of the composite were investigated in the temperature range from room temperature up to 300 °C. Transmission electron microscopy revealed cuboidal precipitates in the matrix. Various strengthening mechanisms originating from the matrix and the reinforcing particles are discussed.

*Keywords:* Magnesium alloy based composite; Orowan strengthening; Load transfer; Thermal stresses

## 1. Introduction

Low-density materials become increasingly important for various structural applications in transport and electronic industry, especially in cases where weight or energy must be saved.

When high mechanical properties are also required, magnesium–rare earth (Mg–RE) alloys appear as very good candidates. They reach high specific strength, creep resistance, good castability, and corrosion resistance up to a temperature of 250 °C. In these Mg alloys, strengthening results from a dense fine scale precipitation, which remains quite stable up to 5000 h in the 200–250 °C range [1]. Among the Mg–RE alloys, the Mg–Y–Nd system provides a combination of mechanical and corrosion properties, which allows the development of commercial alloys: WE43 (4 wt.% Y, 3.3 wt.% RE, 0.5 wt.% Zr) and WE54 (5.25 wt.% Y, 3.5 wt.% RE, 0.5 wt.% Zr), where RE consists of mischmetal (essentially Nd).

Considerable improvement of the mechanical properties can also be achieved by reinforcement with ceramic particles or fibres. Metal matrix composites (MMCs) provide a substantial increase in strength and stiffness as well as creep resistance. The ductility of composites is significantly reduced as compared to unreinforced alloys. Magnesium matrix composites show better wear resistance, enhanced strength and creep resistance and keep a low density and a good machinability [2]. Investigation of their mechanical and physical properties is important not only for applications but also for a better understanding of the processes responsible for their behaviour.

In the present pages, structural and mechanical properties, especially the compression response of SiC particulates-strengthened magnesium alloy WE54, are reported. The role of various strengthening terms is discussed.

## 2. Experimental procedure

The WE54 alloy reinforced by SiC particles with a volume fraction of 13%, was processed by a powder metallurgy method. Mixing of the matrix powders with various SiC particles was carried out first in an asymmetrically moved mixer with subsequent milling in a ball mill. The powder was encapsulated in magnesium containers and extruded at 400 °C using a 4 MN horizontal extrusion press. The composite samples were not thermally treated.

Compression tests were carried out at temperatures between room temperature and 300 °C using an INSTRON testing machine. Cylindrical specimens of 8 mm diameter and 12 mm length were deformed at an initial strain rate of $2.8 \times 10^{-4}\ \mathrm{s}^{-1}$. Temperature in the furnace was kept with an accuracy of ±1 K. The microstructure was examined by light microscopy and transmission electron microscopy (TEM). Thin films for TEM analysis were prepared using a precision ion polishing system with an incident angle of 5° and a beam energy of

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doi:10.1016/j.msea.2006.01.182

4.5 keV. A PHILIPS CM200 transmission electron microscope equipped with a double-tilt specimen holder was used for microstructural studies. TEM studies were carried out at 200 kV.

## 3. Experimental results

Fig. 1 shows an optical micrograph of the as-prepared WE54/SiC composite. The SiC particles are not uniformly distributed in the matrix; they form in many cases small clusters. The mean SiC particle size was found to be about 9 μm. As it is visible from Fig. 1, the as-extruded bar appears mainly constituted of very small equiaxed grains (generally ∼3 μm) after accurate optical microscopy observations. No grain growth has been observed during the deformation tests at elevated temperatures. Fig. 2 shows the compressive true stress–strain curves obtained for the WE54/SiC composite deformed at various temperatures. Samples were deformed either to fracture or to predetermined strains at higher temperatures. Significant work hardening has been obtained for temperatures up to 200 °C. The stress–strain curves obtained at higher temperatures have a flat character. The temperature dependences of the characteristic stresses, the yield stress $\sigma_{02}$ and the maximum stress $\sigma_{\max}$, are shown in Fig. 3. The influence of the temperature on strain hardening of the composite is well visible. The yield stress decreases with increasing temperature very slowly up to 200 °C, while the observed decrease of the maximum stress $\sigma_{\max}$ is more rapid. For temperatures higher than 200 °C both stresses decrease substantially. It can be concluded that the thermal stability of the composite is very good up to 200 °C.

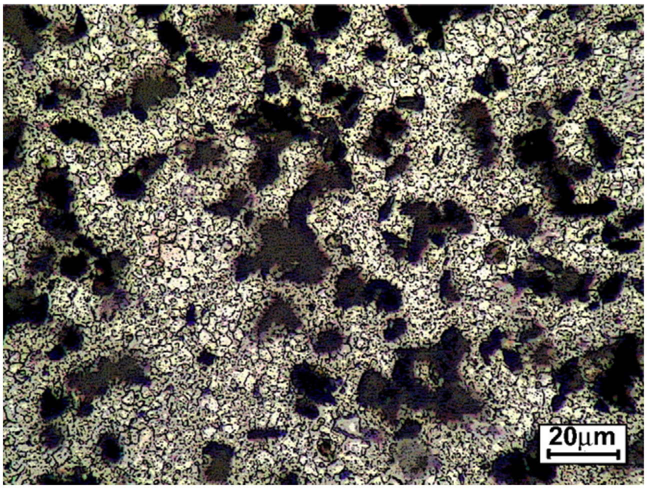

Fig. 1. Optical micrograph of the as-extruded WE54/SiC composite.

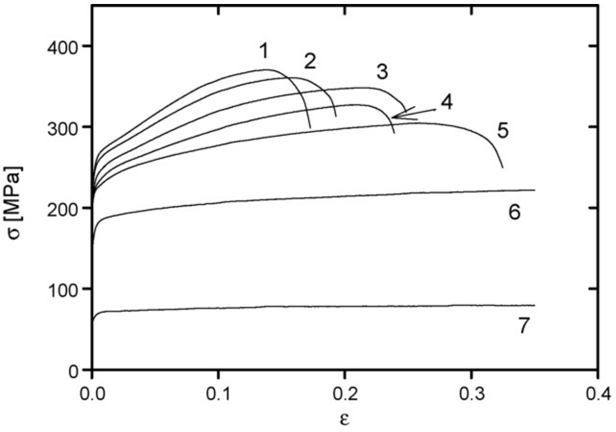

Fig. 2. True stress–strain curves of the WE54/SiC obtained in compression at various temperatures (1–23, 2–50, 3–100, 4–150, 5–200, 6–250 and 7–300 °C).

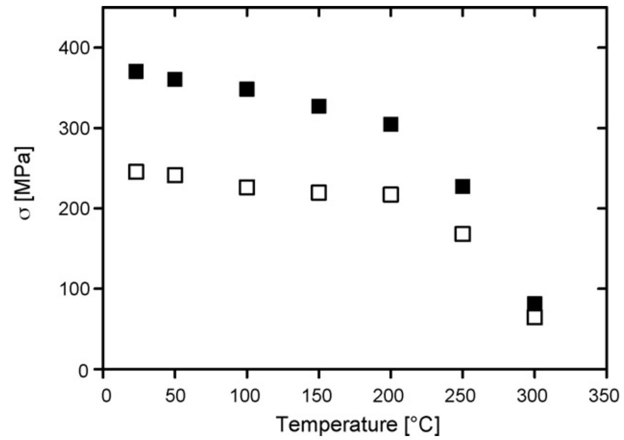

Fig. 3. Temperature dependence of the yield stress (empty squares) and the maximum stress (full squares).

TEM microstructures of the non-deformed composite sample and samples deformed in compression at 50 and 150 °C are shown in Figs. 4–6, successively (typical bright field images). TEM investigation revealed that the presence of many twins is a common feature for both non-deformed as well as deformed composites. Grains in the as-received material are well visible in Fig. 4. Thin twins, within single grains, are parallel to each other

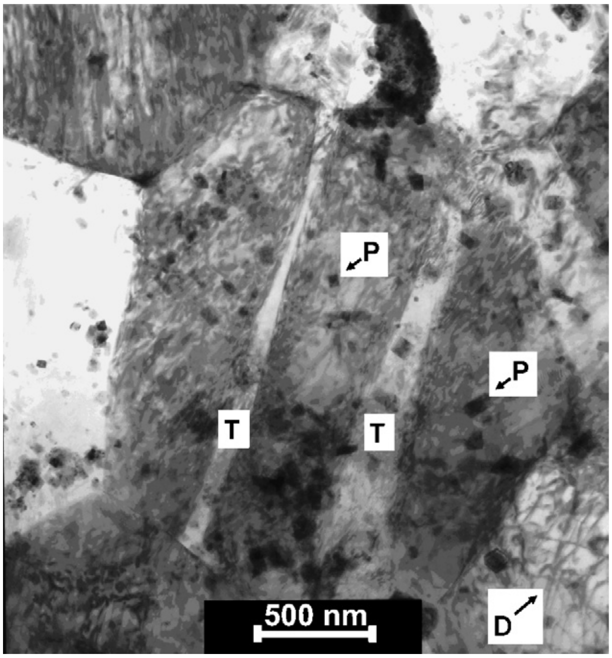

Fig. 4. Transmission electron micrograph of the as-prepared composite—representative image showing the presence of twins (T) and precipitates (P). Tangled dislocations (D) in the right bottom corner are visible.